7th International Conference on Production Research - Americas

THE LEAN PRODUCTION MULTIDISCIPLINARY: FROM OPERATIONS TO EDUCATION

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Abstract

Lean Engineering (LE) had its roots in Toyota automobile production where the main objective is to standardize operations, so that wastes in the production processes can be identified and eliminated. Pursuing standardization in a systematically and continuous way, companies enter a continuous improvement mode of operation where input from all affected parties across the value stream is sought; this requires personnel on all levels of the organization to be prepared to be active learners. As LE has exceeded its original focus and application in the automotive industry, it has transformed manufacturing industries as well as service providers, including travel agents, health care, and many others. Yet, although engineers and non-engineers alike rely on LE principles and tools almost daily, LE has not yet transformed Engineering Education. In this paper, the authors review their concept of Lean Engineering Education which they have based on the three-step of ethics, system-thinking and sustainability. The paper concludes with recommendations for curriculum innovations to improve engineering students' competencies.

Keywords:

Lean Production; Lean Engineering Education; engineering competencies.

1 INTRODUCTION

Lean Production (LP) had its origin in Toyota Production System [1] [2] of Toyota company. After the Second Great World War. Toyota had to change its approach to production to maintain its automobile production, as the resources were scarce. Its key idea was to "doing more with less" where "less" means fewer resources, less inventory, less human effort, less space, less of everything than their American counterparts [3].

Attending to this idea, Lean Production was the term adopted later in the best-seller "The Machine that Changed the World" from Womack and colleagues [3]. Toyota way to achieve a "lean" approach was to eliminate all wastes, i.e., activities that adds no value to the product from customer point of view. This allows reducing cost and increasing productivity. Nevertheless, waste elimination is not enough because this needs a context and a culture, known and understandable by all stakeholders (top management, co-workers and suppliers). Toyota way is so described in a model, represented in a pyramid that represents from the base to the top the Toyota culture. This is 4P model: 1) a long-term thinking Philosophy; 2) continuous Process improvement to eliminate waste; 3) People and Partners respect, challenge and grow; 4) Problem-solving by continuous improvement and learning [4].

Thus, learning is part integrated of Toyota model, being this a concern in Toyota companies that had been developing an Education model based in "learning by doing" system. This has the objective to transform Toyota employees in a community of scientists following the scientific method. These were allowed to experiment and learn with their mistakes [5]. This learning system inside company doors has been the Toyota success and inspiration for many manufacturing industries and services providers to follow. From an incremental and analytic building process of continuous improvement through Toyota Education Model development, the authors of this paper see Lean as a body of knowledge that provides a framework for Lean Thinking to emerge in Engineering Education (EE). As objective of EE is training the workforce of tomorrow for companies, these must be trained in Lean principles. Some initiatives to integrate Lean in curricula have been put forward and this paper will review them.

Additionally, as the authors considered these initiatives are not enough, in this paper, the authors present and review their concept of Lean Engineering Education which they have based on the three-step of ethics, system-thinking and sustainability. The paper concludes with recommendations for curricula innovations to improve engineering students' systems thinking competencies.

This paper is organized in five sections. After this introduction, the authors present a brief literature review about Lean Production (LP) and implementations cases of Lean. The section three outlines the theme of this paper, the LP multidisciplinary, based on the disciplines/areas that had been applying Lean concepts and principles. Furthermore, explore the Lean education area as the most fertile area. Based on this, the authors propose their Lean Engineering Education concept in section four. Some conclusions are presented in section five.

2 LITERATURE REVIEW

This section presents a brief literature about Lean Production definition, principles and tools. Additionally, some implementation cases and benefits are presented.

2.1 Lean Production definition, principles and tools

The National Institute of Standards and Technology (NIST) [6] defined Lean Production as *"… a series of tools and techniques for managing your organization's processes. Specifically, Lean focuses on eliminating all non-value-added activities and waste from processes. Although Lean tools differ from application to application, the goal is always incremental and breakthrough improvement. Lean projects might focus on eliminating or reducing anything a final customer would not want to pay for: scrap, rework, inspection, inventory, queuing or wait time, transportation of materials or products, redundant motion and other non-value-added process steps."*

In this definition the wastes are also presented which were defined the first time by Ohno [2]. Additionally, others authors, namely Liker [4] had been defined others wastes such as untapped human potential that it is considered the most serious waste as inhibits companies to evolve. In this human potential is the ability of people to learn and continuously improve to achieve perfection. Pursuit perfection is the fifth Lean Thinking principle from Womack and Jones [7]. The other four are: Value – identify what is the value for the client; Value Stream – identify the activities that adds value to the products; Continuous flow – means a smooth and levelled workload without waste and 4) Pull system – this means that it is the client that trigger the services delivery and content. Applying systematically these principles, companies continuously improve in order to aspire perfection.

Knowing these principles, companies must also have competency to apply the correct tools to achieve each principle. There are many tools available such as standard work, visual management, 5S, kaizen, quick changeover (QCO), single minute exchange of die (SMED), poka-yoke mechanisms, levelling, among others [8]. Then it is necessary to know when and how to apply them [9] [10] in order to walk in the right way for Lean implementation well-succeed.

2.2 Lean Production implementation cases and benefits

Lean Production had been implemented in almost all manufacturing industries and services providers. Some examples (case studies, surveys,…) from literature are too many, evidencing the cross-sectional and globalization of Lean application (Table 1).

Table 1: Examples of Lean application

Reference	Industry/service	Country
Sohal [11]	Automotive parts	Australia
Swank [12]	Insurance and annuities	USA
Emiliani [13]	Business school courses	USA
Melton [14]	Process industries (chemicals & pharmaceuticals)	UK
Doolen & Hacker [15]	Electronics Manufacturers	USA
Bonavia & Marin [16]	Ceramic tile industry	Spain
Abdulmalek & Rajgopal [17]	Process sector (large integrated steel mill)	Kuwait
Ziskovsky & Ziskovsky [18]	School operations and program outcomes	USA
Flumerfelt [19]	School processes	USA
Farhana & Amir [20]	Garment	Bangladesh
Wong et al. [21]	Electrical and electronics	Malaysia
Waldhausen et al. [22]	Health care (pediatric surgery)	USA
Pool et al. [23]	Semi-process	Netherlands
Romero & Martín [24]	Aeronautics	Spain
Hodge et al. [25]	Textile	USA
Vinodh et al. [26]	Automotive valves	India
Carvalho et al. [27]	Metal structures	Portugal
Staats et al. [28][29]	Software services	India
Veža et al. [30]	Bottler beverage	Croatia
Chowdary & George [21]	Pharmaceutical	Trinidad and Tobago
Martins & Carvalho [31]	Courts Law	Portugal
Bortolotti & Romano [32]	Banking services	Italy
Ribeiro et al. [33]	Wood furniture	Portugal
Lyons et al. [34]	Process industry	UK
Bragança et al. [35]	Elevators	Portugal
Blank [36]	Entrepreneurship activities	USA
Kusler [37]	University processes	USA
Alp [38]	College of Engineering processes	USA

Additionally, some surveys cross-sectional industries have been published, namely, Panizzolo [39] [40]; Shah & Ward, [41]; Liker & Morgan [42]; Page [43]; Taj [44]; Silva et al. [45]; and Mathur [46].

Benefits achieved by these companies are oriented to the reduction of costs and improvement of productivity. This means reducing all wastes such as reduced transports, defects, motions, inventory, over-processing among others [47]. Such benefits allow companies obtain more profits without increase the resources or firing people.

3 LEAN PRODUCTION MULTIDISCIPLINARY

This section presents disciplinary areas that had been applying LP. Moreover, it presents its application in Educational curricula in some universities.

3.1 Disciplines/areas

It was evident from above that LP is cross-sectional and global. Furthermore, Lean Thinking (LT) is being adopted in many disciplines/areas:

- Lean Services – applied to services (offices, hospitals, schools, restaurants,…)
- Lean Office – applied to administrative processes in office; normally is included in the first category
- Lean Higher Education – applied to universities processes; normally is included in the first category
- Lean Construction – applied to construction of houses, roads, bridges, ships and others products of large dimension in a fixed site (or project) type layout
- Lean Green – applied to achieve the sustainable development (toolkits of U.S. – EPA)
- Lean Coaching – applied to training and people development
- Lean Six Sigma – applied to process improvement
- Lean Supply Chain Management/Lean Logistics – applied to supply chain and warehouse management
- Lean Accounting – applied to accounting
- Factory of One/Personal Kanban – applied to individual performance
- Lean Startup – applied to software development and companies entrepreneurship
- Lean Education – applied to Education

The success of LP is related with its inherent philosophy, Lean Thinking as this implies a culture change and a new mind-set. Any company that embraces LT will be in a continuous improvement effort where everything is questioned by all people. People is transformed in truly active thinkers and learners [48] that will continuously search problems to solve, being always unsatisfied with status-quo. Doing this in a systematically and continuous way, companies, organizations and institutions will be prepared to face the global challenges which technological progress is not capable to solve, and that, sometimes, provokes more damage than good. Therefore, it is not a surprise than Lean Thinking principles and tools had been adopted and combined in so many disciplines.

3.2 Lean Education

Many authors have been integrating Lean Production in students education through some courses included in the program. They have this concern as they felt to train the workforce and to educate students in LP is an imperative to face the new industrial challenge. At the same time, they are providing industrial companies with better prepared students capable to work in Lean environments and avoid companies to spend money in employees training.

For these reasons, Lean Education has been a concern of some important initiatives and networks. Lean Aerospace Initiative (LAI) Educational Network (EdNet) is one of these networks. This was established in 2002 and comprised 32 universities (from US and UK) who share a common interest to collaborate on developing and deploying curriculum for teaching lean six sigma fundamentals [49]. In a faculty collaboration effort, supported by a small staff centered at MIT, a LAI Lean Academy® a week-long course was developed. This course was delivered to multiple audiences on-campus and in industry and government. They based this in CDIO approach (Comprehend/Conceive, Design, Implement and Operate) [50].

Murman et al. [49] discusses Body of Knowledge (BoK) for Lean Thinking arguing that this BoK is not based upon laws of physics and chemistry and is not represented by sophisticated mathematics. This is due to its roots that are based on processes and people/organizational dynamics for which there are no laws. According to them, it relies on understanding "best practices" which are observed through field research of actual enterprises. These best practices are not invariant with time, which means the BoK is subject to change. They also add that much like many engineering science disciplines, information technology is big factor in the current evolution of the BoK.

Another network is Lean Education Academic Network (LEAN) [51]. LEAN is a group of university educators seeking to promote Lean education in United States higher academia. LEAN also helps improve Lean education through sharing of knowledge and teaching materials, collaboration, and networking among colleagues.

These networks, together with Lean Enterprise Institute (LEI) that has been also concerned with Lean Education [52] are sponsoring a conference – Lean Educator Conference (LEC) with the objective of sharing best practices in Lean curriculum and pedagogy (http://www.leaneducatorconference.org/news/99-2014-lean-educator-conference-call-for-papers.html).

Moreover, a project joined Dutch, Swedish, Polish, Portuguese and Romanian universities and companies in a project in the framework of an Erasmus–Lifelong Learning Program (LLP). Martens [53] presents the report of this project considering this an innovative training program on Lean Manufacturing. The objectives of Lean Learning Academy [54] [55] with this project are to satisfy the need for training lean manufacturing principles in companies and to improve engineering students' employability in professional life.

Table 2 presents some publications about programs, courses or modules that had been adopted to teach Lean Production concepts, principles and tools. Additionally, in this table are presented the learning methodologies used to teach these concepts. It is important to notice that LP demands active learning methodologies [56] to engage actively students in their own learning and in collaborative learning.

Moreover, it is also evident that project work in a company (industrial environment) is frequent as a learning methodology. This is not a surprise because as already explained in the first section (Introduction), Toyota Education Model is a "learning by doing" system. According to some authors, namely Huntzinger [57], this system was adopted from the model Training With Industry (TWI) for training people in industry developed to support U.S. industry during World War II and Lean roots and kaizen were grounded on this model.

According to Suzaki [58] people in companies are simultaneously assuming the role of a trainer and trainee, teaching and learning with each other. This is necessary to empower people and continuous improvement. The concern with people learning is continuous as companies only grow with this. *"Making people before making products"* can be read in Figure 1 that shows a picture from the book of this author.

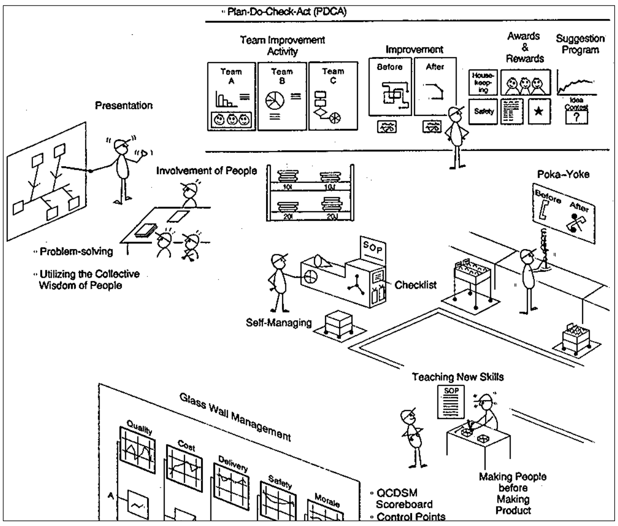

Figure 1. The new shop-floor management vision (aspect from [58])

Table 2: Publications about Lean programs, courses and modules taught and learning methodologies used to do this

Authors/year	Program/course/modules taught to:	Learning methodologies
Torres & Stephens, 2005; 2006 [59] [60]	Industrial Technology students; Business process managers - graduate	Lecturing, analysis of cases and the study of real business situations; basic cognitive skills (concepts and theories); project selection and execution
Lobaugh 2005;	Technical elective for all undergraduate	Lectures and simulations; group participation and investigation of actual industrial applications

2008 [61][62]	engineering major; elective for the masters level	of lean practices
Van Til et al. 2005 [63]	Engineering, business, and human resource development degree programs: engineering M.S. (computer, electrical, mechanical, and systems), MBA and Masters in Training and Development (MTD)	Semester long project: analyzes of the performance of a local manufacturing company and develops a plan for implementing a lean program
Fang et al. 2006, 2007 [64][65]	Colleges of Engineering and Business	Plant tours, guest lectures, real-world industrial projects, Lean Lego Simulation (LLS)
Mehta & Monroe 2006 [66]; 2009 [67]	Distance education students and nonmanufacturing employees	Virtual Simulation; simulation utilizing a simple product made from Lego® blocks
Miles & Hawks 2006 [68]	Undergraduate students	Classroom lectures with industry-based projects
Candido et al. 2007 [69]; McManus et al. [70]; Murman et al. [49]	Audience with little or no experience in LP: undergraduate & graduate engineering students; MBA students; coops and interns new employees; long term employees; military personnel	Plant tours, the supply chain puzzle, mechanical assembly for lean engineering; team exercises, hands-on simulations, case studies, interviews with lean experts and class presentations
Chen & Cox 2008 [71]	College of Engineering	Lecture and lab activities; onsite project in a local company
Hall & Holloway 2008 [72]	Undergraduate and graduate engineering; non-engineering students (from business or medicine)	Inquiry Learning; simulated factory experiences and through visits to manufacturing facilities
Peters et al. 2008 [73]	Industrial engineering students	Hands-on, visual, and experiential-based assignments; project work in companies
Thomas 2008 [74]	graduate-level	Lab exercises
Martens [53]	Engineering students	Simulation games and course modules
Johnson 2010 [75]	Industrial engineering	Inquiry learning; hands-on materials; case studies and a short game
Leduc et al. 2010 [76]	Manufacturing Engineering Technology (MfgET) capstone	Immersive learning projects
Peter 2010 [77]	Graduate students with different undergraduate educational backgrounds including individuals with no prior industrial experience	Hands-on industry-based case studies
Cudney et al. 2011 [78]; Gadre et al. 2011 [79]	Undergraduate curricula: Engineering Management, Industrial Engineering, and Mechanical Engineering	Integrated user-centered virtual learning environment through extensible simulation learning modules; hands-on projects and simulation games
Mozammel et al. 2011 [80]	Industrial engineering technology	Real-world laboratory experiences; directed project
Allam et al. 2012 [81]	First-year Engineering	Hands-on quality and productivity lab
Vila-Parrish & Raubenheimer 2012 [82]	Industrial and Systems Engineering (ISE)	Capstone project experiences
Wan et al. 2012 [83]	College students and industry personnel	Simulation game

These publications evidences that incorporating Lean Thinking in Engineering Education is utmost a value proposition for engineering students to develop competences needed by industry and society, now and in the future. This is discussed in the next section.

4 LEAN ENGINEERING EDUCATION

Lean Education presented previously showed many examples of the concern in including Lean in engineering and other curricula. This offer benefits for the academy that include the improvement of course design/delivery based on problem/project-based learning and of the overall quality of the learning experience based on student-centeredness competences.

Beyond this, authors of this paper proposed the Lean Engineering Education (LEE) concept. LEE is the term labeled by the authors of this paper to Lean applied to Engineering Education curriculum design. Lean Engineering Education is defined in book 'authors in progress [85] as:

"A systematic, student-centered and value-enhanced approach to educational service delivery that enables students to holistically meet, lead and shape industrial, individual and societal needs by integrating comprehension, appreciation and application of tools and concepts of engineering fundamentals and professional practice through principles based on respect for people and the environment and continuous improvement." .

When students are taught in LEE, they are enabled to develop problem solving skills [86], to think systemically, ethically [87; 88] and in a sustainable manner [89]. It is advanced that Lean Engineering Education will provide students with three essential competencies: 1) ethics, 2) systems thinking and 3) sustainability. These competencies mastery must be interrelated with the content mastery in a way that resembles a double helix DNA (Figure 2).

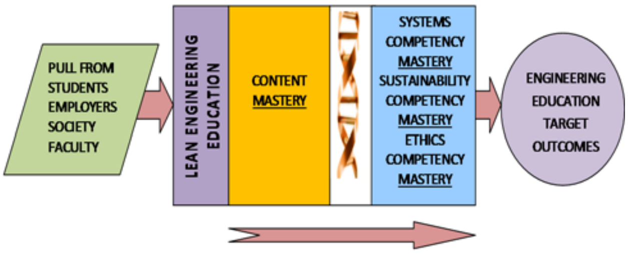

Figure 2. Content and Competency Mastery combined in a double helix DNA [Authors1]

According Rychen & Salganik [84] competence refers to the ability to meet demands of a high degree of complexity, and implies complex action systems. The notion of competencies encompasses cognitive but also motivational, ethical, social, and behavioral components. It combines stable traits, learning outcomes (e.g., knowledge and skills), belief-value systems, habits, and other psychological features. In this view, basic reading, writing and calculating are skills that are critical components of numerous competencies. So, acquiring competences means students learn to respect others (humans beings or other lives), they learn to solve problems and they learn to think in a waste-free manner in everything they do, whatever they do. They learn to think globally forwarding the accomplishment of the 3P (People, Planet, Profit).

5 CONCLUSIONS

This paper presented the multidisciplinary of Lean Production. Today, Lean Thinking is viewed as a philosophy, as a mind-set. LP is in the companies not as a new mode but a new paradigm implying changes to behavior and attitudes of all stakeholders. When this change didn´t happen in this way the old habits come again. Engineering students are the future professionals of the companies and their learning must be aligned with industry and society needs. Being taught in Lean Engineering education, concept proposed by the authors of this paper, students will develop competences and will have the ability to meet demands of a high degree of complexity.

6 ACKNOWLEDGMENTS

This work was financed by National Funds - Portuguese Foundation for Science and Technology, under Project Pest-OE/EME/UI0252/2011.

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